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U.S. ARMY AVIATION SYSTEMS COMMAND
CONTR. #DAAJ09-87-C-A072

T55-L-714 ENGINE
DEVELOPMENT AND QUALIFICATION

CDRL A006
TIP CLEARANCE ANALYSIS
LYC T55-88-04

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31 MAY 1988

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CDRL A006
TIP CLEARANCE ANALYSIS
LYC T55 88-04

AVCO Lycoming textron
Stratford CT

31 MAY 1988

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1.0 OBJECTIVE

The performance of the T55-L-714 engine has shown to be strongly influenced by gas turbine running tip clearance. In order to ensure both optimum steady state performance and to prevent rubs of the gas producer turbine upon rapid deceleration and acceleration, a steady state and transient tip clearance analysis has been conducted. jet engines, ([illegible]) ←

2.0 ENGINE CONFIGURATION

The gas producer turbine section of the T55-L-714 engine is shown in Figure 1. The cooling flow network includes the reduced disc bore cooling design described in References 1 and 2. The rotor and cooled cylinders are shown in Figure 2.

The cooled 1st stage GP cylinder is shown in Figure 3. Cooling air (0.5%) of core flow enters through a number of slotted passages on the cylinder flange. Initially the air flows radially inboard and then forward to the cylinder leading edge where it enters the labyrinth flow passages. The air in the labyrinth passages flows mainly in the circumferential direction in the grooves formed between the barriers, as it proceeds from passage to passage to the cylinder trailing edge. At the cylinder trailing edge, the air discharges and enters the gas stream as film air on the 2nd nozzle outer shroud.

The second stage GP cooled cylinder is shown in Figure 4. Cylinder cooling air (2.4%) enters through a series of holes on the cylinder outside wall near the flange location. The air flows initially downstream and then upstream following a flow path which wraps around the cooling insert. The air leaves the cylinder near its leading edge and flows into the second stage nozzle vane leading edge cooling flow passage for vane cooling. Since the 2.4% of cooling air for the second stage cylinder is the same air used for the nozzle vane cooling, this airflow is increased by only 0.7% over the current 1.7% flow for cooled nozzle in the -712, yielding a total of 2.4% flow in the cooled cylinder and nozzle configuration.

3.0 ANALYSIS METHOD

The turbine disc, seal plate, rotor blade, and cooled cylinder have been analyzed for their growths and effects on the turbine tip clearance under worst engine steady state and transient conditions. The assumed operating cycle in shown in Figure 5. Engine parameters during acceleration and deceleration are shown in Figure 6.

A mathematical (nodal) model representing engine geometry was constructed from engine drawings. Material nodes were established to represent the cylinders, turbine blades, discs and seal plate. Fluid nodes were added to describe the boundary conditions surrounding the turbine wheel and cylinder for both stages. Transient conditions of flow rate, gas temperature and coolant temperature were imposed on the fluid nodes.

A computerized method (Ref. 3) was used to perform the mathematical simulation. The analytical method is described in (Ref. 5) where tip clearance measurements were made with an optical device and favorably compared with calculated predictions. Using this method, temperature distributions were computed for each node based on the transient and steady state conditions. Thermal and centrifugal growths were established in the radial direction and resultant tip clearances determined.

4.0 RESULTS

4.1 CYLINDER TEMPERATURES

Cylinder temperatures were computed for all operating conditions and are shown at sea level, take off (maximum power), 130°F day for the worst engine operating condition. Average circumferential thermal conditions are used in the analysis.

The first stage GP cooled cylinder metal temperatures are shown in Figure 7(a). The -714 cooled cylinder has an average metal temperature of 1480°F, whereas, the -712 average metal temperature for the uncooled cylinder was 1750°F.

The second stage GP cooled cylinder metal temperatures are shown in Figure 7(b). The -714 cooled cylinder has an average metal temperature of 1580°F while the -712 uncooled cylinder had an average metal temperature of 1670°F.

4.2 COMPONENT GROWTHS

The radial growth in the turbine stage can be described in terms of the following components: disc, serration (eg. disc, rim and blade shank), blade airfoil and cylinder. Plots of component growths for the first and second GP turbine stages are shown in Figures 8 & 9. Transient conditions with a steady state stabilization were evaluated: a) steady state ground idle b) ground idle to take off c) steady state maximum power and d) take off to ground idle. Discussion of the growth characteristics for each of the components follows.

The centrifugal growth of the rotating system is instantaneous with the speed change. The resulting elastic growth of the rotor system is maximum at highest speed. The thermal response of the components is dependant on the rate of gas or air temperature change surrounding the component as well as the thermal lag of the component. Thermal lag is increased with component mass and to a lesser extent is reduced by high heat transfer rates, which occur when exposed to large heat transfer coefficients.

The disc accounts for a major portion of the rotating system growth. During transients the large mass of disc compared with the other components causes it to lag in thermal growth. This causes the exponential decay shape of its transient growth plot, which typically stabilizes after several minutes.

The serration (disc rim and blade shank) growth is small since the radial length of this area is small. Although this area is moderate in mass, it still has a lag in thermal growth due to small heat transfer coefficients and relatively good thermal contact with the disc. Thus, its growth rate closely follows that of the disc. The serration growth is seen as a curve slightly above the disc curve in the plots.

The blade experiences the other major portion of the rotating system growth. The blade centrifugal and thermal response is rapid; the blade thermal change occurs in less than 10 seconds.

Cylinder growth is due only to thermal growth. The purpose of cooling the cylinder is to reduce its growth during all of the engine operation; thereby reducing tip clearance. The transient response of a cooled cylinder is slower than that of the uncooled one, because the air cooling heat transfer coefficient is higher in the cooled cylinder. In the T55-L-714, the cylinder's response rate is intermediate between that of the blade and disc.

In general, the observations from Figures 8 and 9 are similar and follow the above discussion. Minimum clearance occurs during transient conditions.

4.3 TIP CLEARANCE

The differential growth of the cylinder minus the blade tip is shown in Figures 10 and 11 for the first and second GP turbine stages respectively. This represents "relative" tip clearance assuming zero assembly clearance. Allowances for eccentricity, rotor blade run-out and cylinder distortion under hot running conditions are routinely made to avoid blade tip rubs. Through engine test experience with the cooled cylinder, it appears that approximately 0.020 inch must be allowed to avoid local distortion in the hardware. To obtain this value, an assembly clearance of 0.021 inch and 0.022 inch is required for the first and second GP turbines respectively.

Two mission profiles were considered for the tip clearance analyses: a sea level standard 59°F and 130°F day. As expected, tighter tip clearances were found to exist for the 59°F day transient profile due to cooler compressor exit temperature and subsequent lower cylinder metal temperatures. Relative, assembly, and operating tip clearances are summarized in Tables I and II for the first and second GP turbine stages. The minimum clearance for the T55-L-714 first GP cooled cylinder occurs during deceleration from take off, steady state to the ground idle power condition. Minimum tip clearance for the second GP cylinder occurs during acceleration from steady state, ground idle to take off, maximum power.

An engine performance benefit is expected based on steady state operating tip clearance reduction due to redesign from the -712 uncooled to the -714 cooled cylinder configuration. The first stage GP turbine tip clearance reduction from the -712 to the -714 was from 0.079" to 0.031" respectively. This is equivalent to 3.5% of blade height. The second stage GP turbine tip clearance reduction was from 0.057" to 0.027", which is equivalent to 1.7% of blade height.

5.0 CONCLUSIONS

Using the cooled cylinder design in the -714 engine will improve its performance due to the following analytically determined advantages:

- Lower cylinder metal temperatures.
- Improved roundness of the cylinder.
- Smaller tip clearances.

Final verification that the cooled cylinder design will enhance engine performance and ensure proper tip clearance control will be accomplished during qualification testing.

6.0 REFERENCES

1. L. Hayes, "T55-L-712 First GP Turbine Disk Temperature Analysis with Reduced Bore Cooling Air", Report No. LYC 81-29, March 1981.

2. "T55-L-712 Performance Improvement via Leakage Reduction", Report No. LYC 82-4, January 1982.

3. E. Hartel, C. Duhaime, W. Corcoran, "Transient Tip Clearance Modeling Program" Lycoming Computer Program F119A, revised March 12, 1980.

4. S. White, "Turbine Tip Clearance Measurement", Report No. USARTL-TR-77-47, Dec. 1977. Final report for AVRADCOM Ft. Eustis, VA prepared by Avco Lycoming Division.

5. A. Chandoke, "T55-L-712: Tip Clearance Analysis of the First and Second Gas Producer Turbine Assembly with Uncooled and Cooled Cylinders without Abradable Coating.", Report No. LYC 83-39, July 1983.

TABLE I.

T55-L-712 FIRST GAS PRODUCER TURBINE TIP CLEARANCE SUMMARY (INCHES)

130°F DAY (G.I. - T.O. - G.I.)

CYLINDER	TIP CLEARANCE	STEADY STATE G.I.	MINIMUM DURING G.I. TO T.O.	STEADY STATE	MINIMUM DURING T.O. TO G.I.
UNCOOLED	RELATIVE	0.034	0.031	0.058	0.030
	MIN. COLD ASSEMBLY	0.021	0.021	0.021	0.021
	OPERATING	0.055	0.052	0.079	0.051

T55-L-714 FIRST GAS PRODUCER TURBINE TIP CLEARANCE SUMMARY (INCHES)

59°F DAY (G.I. - T.O. - G.I.)

CYLINDER	TIP CLEARANCE	STEADY STATE G.I.	MINIMUM DURING G.I. TO T.O.	STEADY STATE	MINIMUM DURING T.O. TO G.I.
COOLED	RELATIVE	0.007	0.003	0.010	-0.002
	MIN. COLD ASSEMBLY	0.021	0.021	0.021	0.021
	OPERATING	0.028	0.024	0.031	0.019

TABLE II.

T55-L-712 SECOND GAS PRODUCER TURBINE TIP CLEARANCE SUMMARY (INCHES)

130°F DAY (G.I. - T.O. - G.I.)

CYLINDER	TIP CLEARANCE (INCHES)	STEADY STATE G.I.	MINIMUM DURING G.I. TO T.O.	STEADY STATE	MINIMUM DURING T.O. TO G.I.
UNCOOLED	RELATIVE	0.020	0.011	0.035	0.014
	MIN. COLD ASSEMBLY	0.022	0.022	0.022	0.022
	OPERATING	0.042	0.033	0.057	0.036

T55-L-714 SECOND GAS PRODUCER TURBINE TIP CLEARANCE SUMMARY (INCHES)

59°F DAY (G.I. - T.O. - G.I.)

CYLINDER	TIP CLEARANCE (INCHES)	STEADY STATE G.I.	MINIMUM DURING G.I. TO T.O.	STEADY STATE	MINIMUM DURING T.O. TO G.I.
COOLED	RELATIVE	0.007	-0.007	0.005	-0.004
	MIN. COLD ASSEMBLY	0.022	0.022	0.022	0.022
	OPERATING	0.029	0.015	0.027	0.018

T55-L-714 COOLING FLOW NETWORK

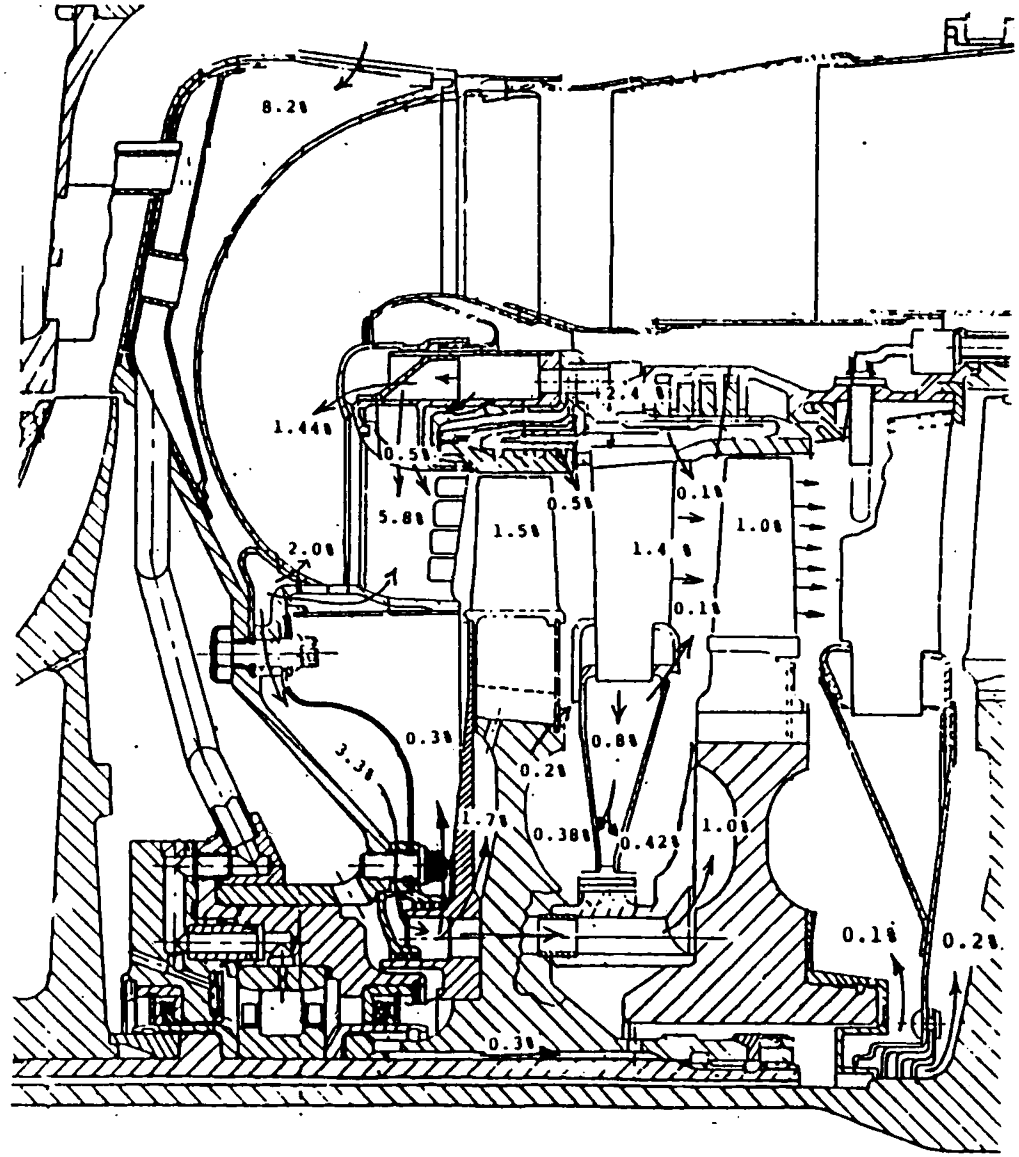


FIGURE 1.

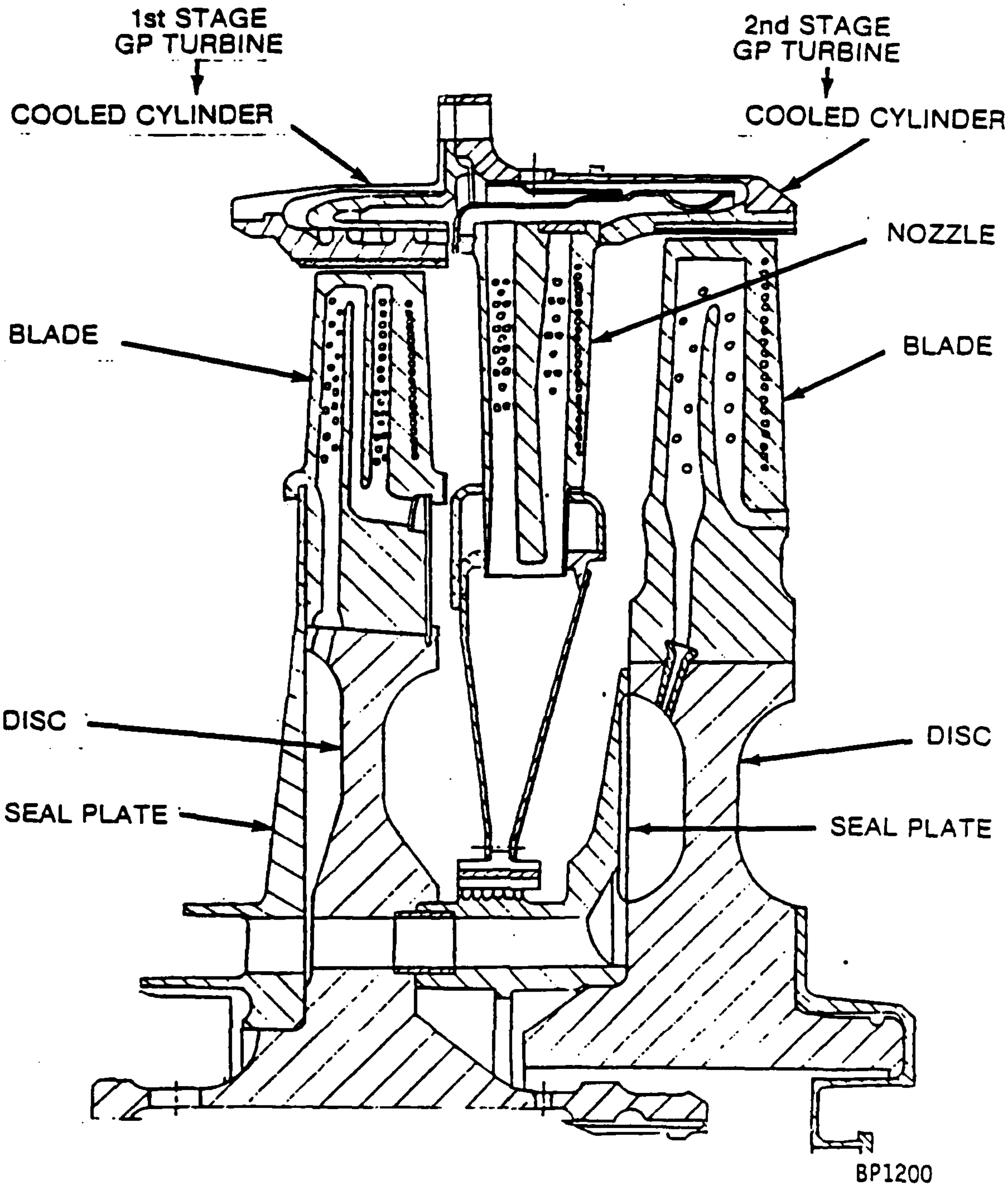
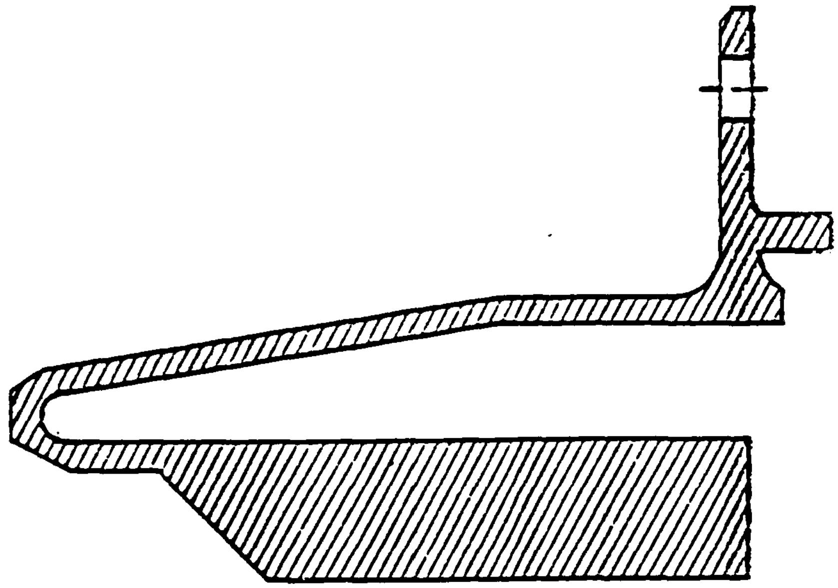
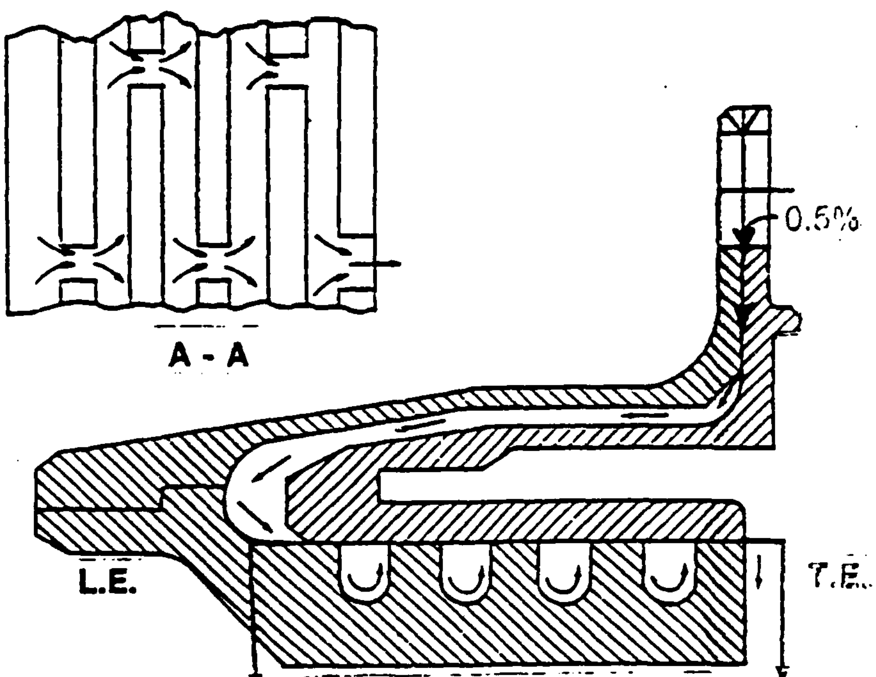


FIGURE 2, GAS PRODUCER TURBINE ROTOR AND COOLED CYLINDER ASSEMBLY

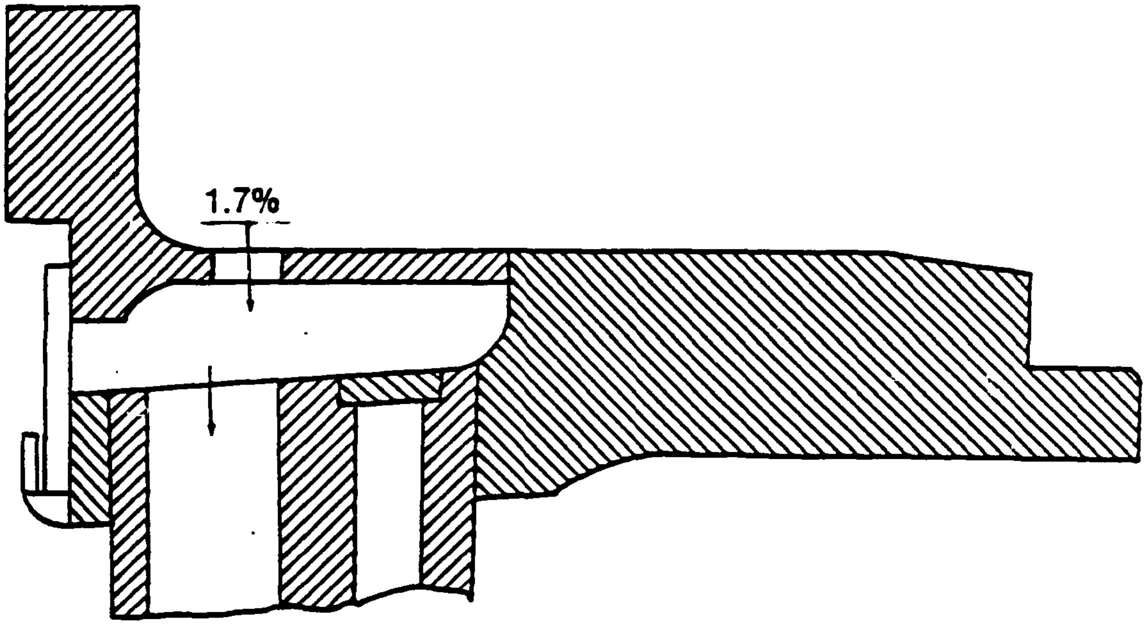


-712 UNCOOLED CYLINDER

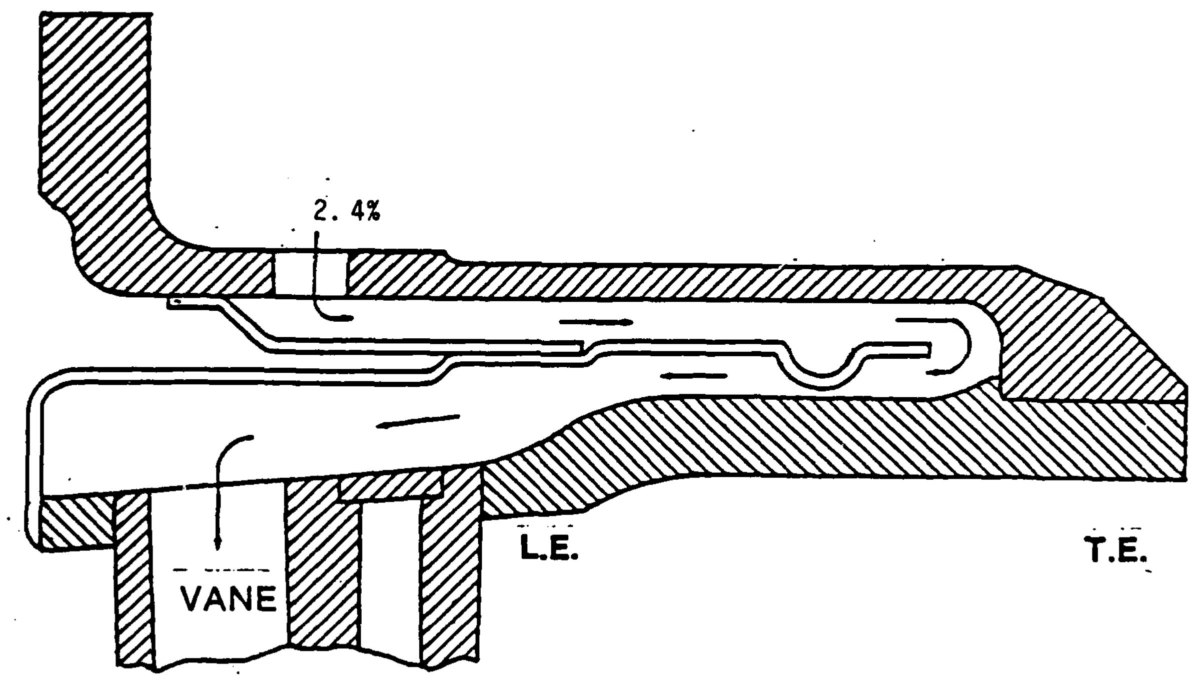


-714 COOLED CYLINDER

FIGURE 3. FIRST STAGE G.P. TURBINE CYLINDERS (UNCOOLED AND COOLED)



-712 UNCOOLED CYLINDER



-714 COOLED CYLINDER

FIGURE 4. SECOND STAGE G.P. TURBINE CYLINDERS (UNCOOLED AND COOLED)

T55 ENGINE OPERATING CYCLE

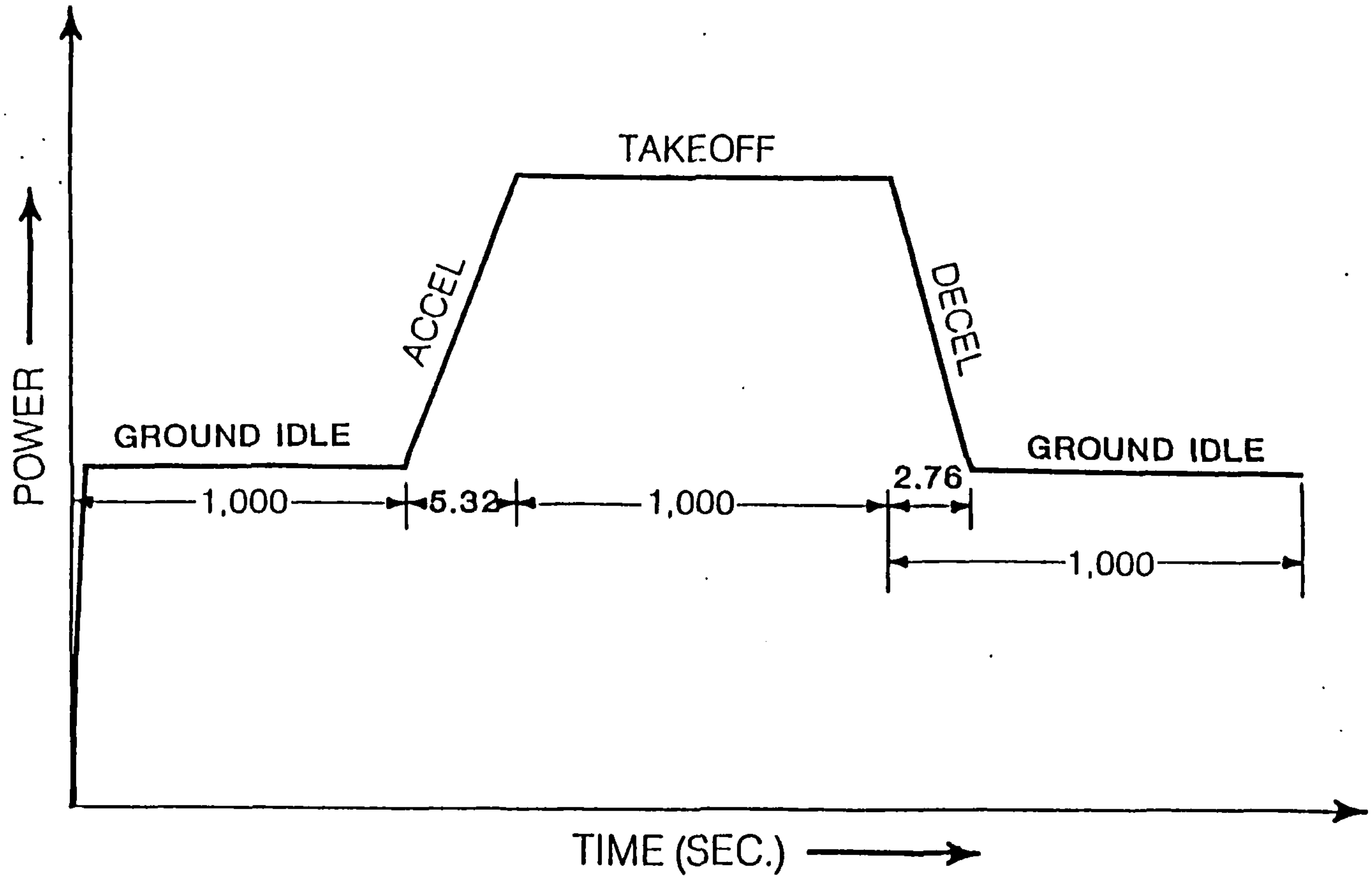


FIGURE 5.

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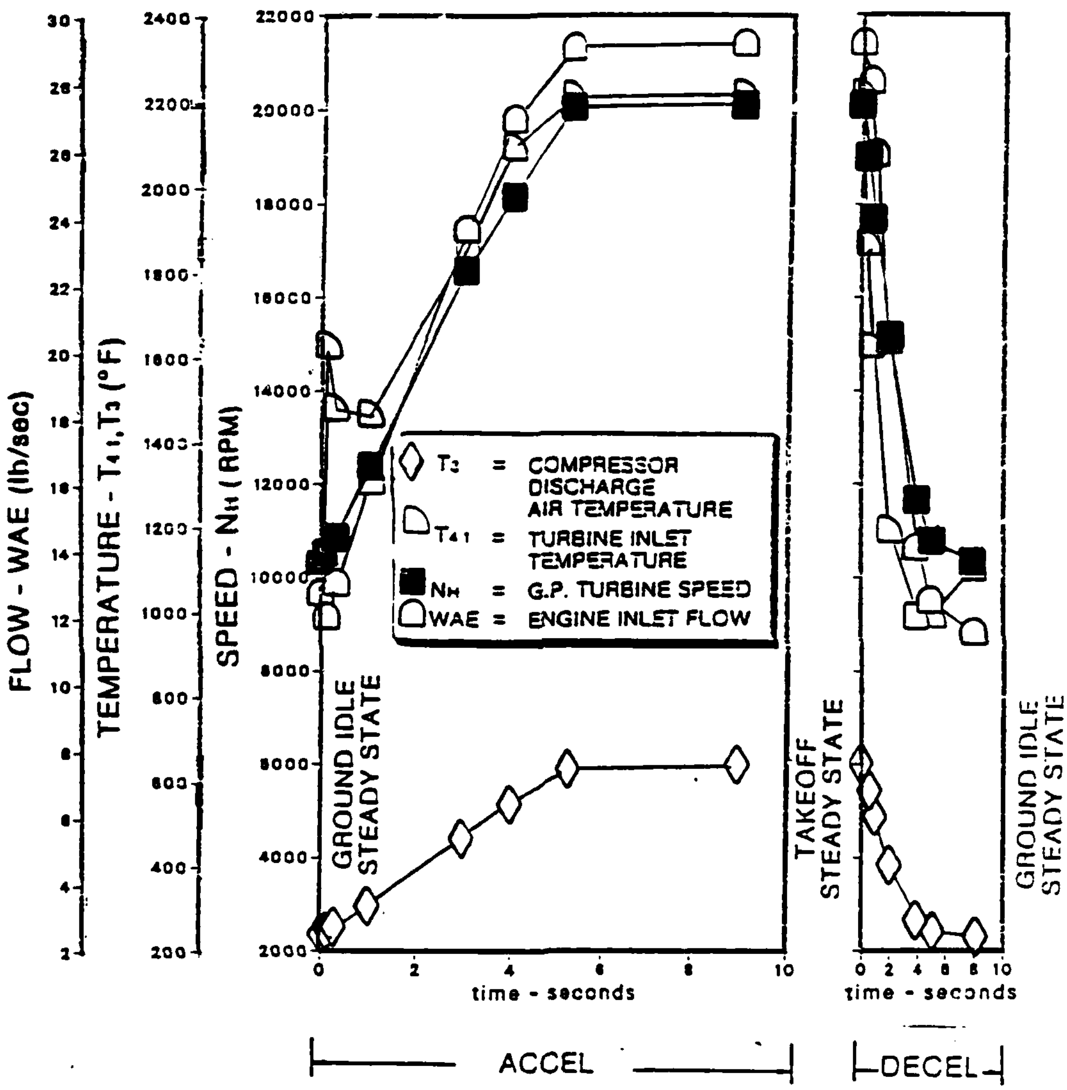
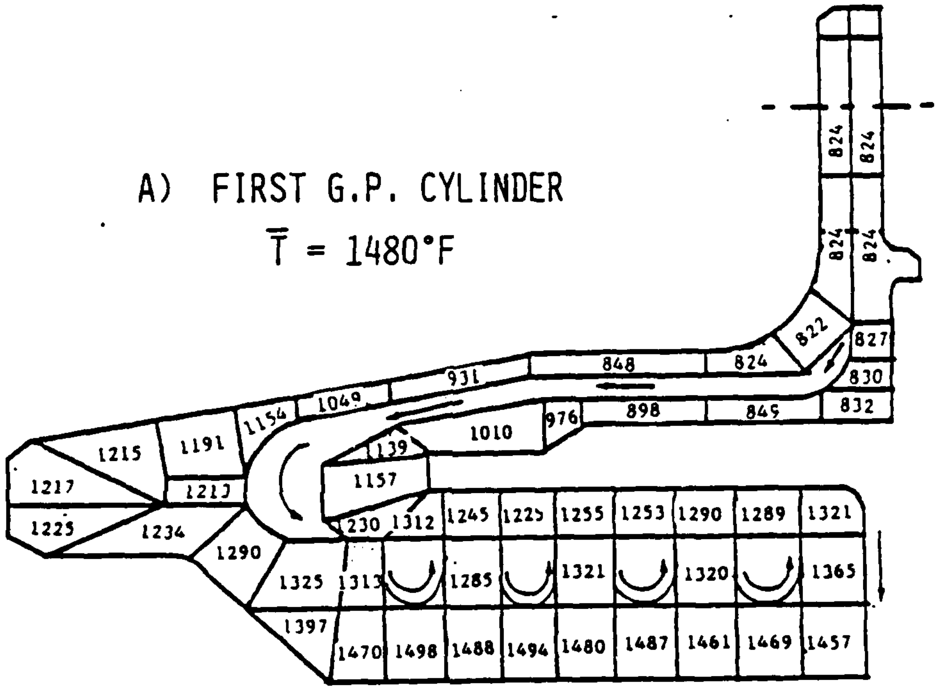


FIGURE 6. T55 PRINCIPAL ENGINE PERFORMANCE PARAMETERS ON ACCEL AND DECEL

A) FIRST G.P. CYLINDER

$\bar{T} = 1480°F$



DESIGN CONDITIONS
130°F HOT DAY SLS TAKEOFF

$T_{4.1} = 2210°F$

$T_{3.0} = 703°F$

B) SECOND G.P. CYLINDER

$\bar{T} = 1580°F$

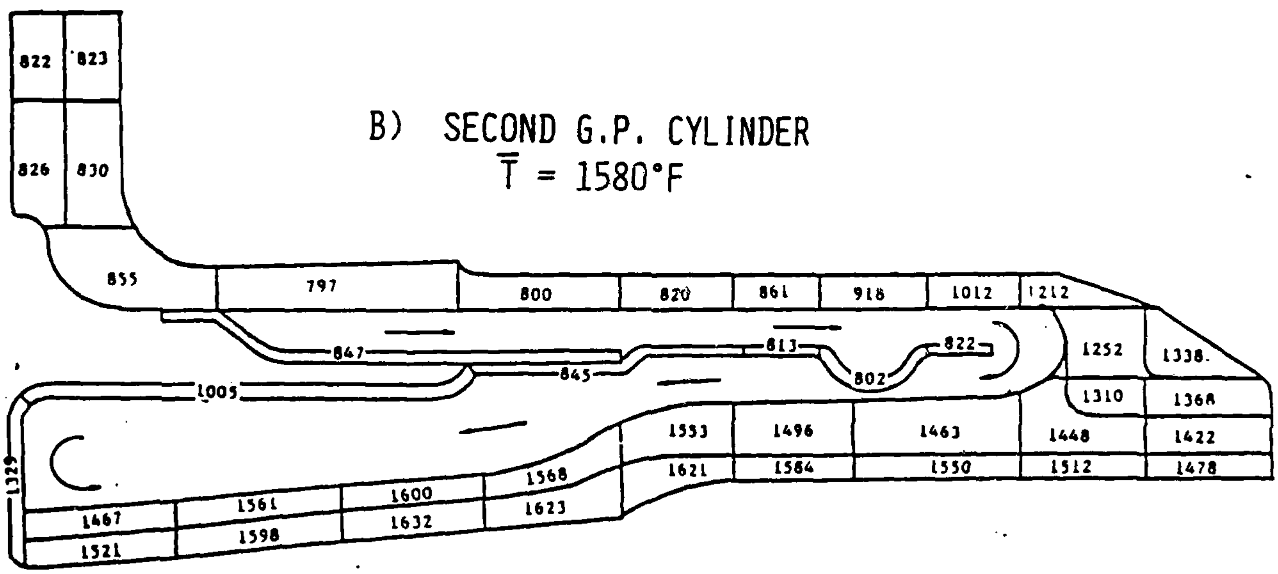


FIGURE 7. FIRST AND SECOND STAGE G.P. TURBINE COOLED CYLINDERS TEMPERATURES (°F) AT TAKE OFF STEADY STATE

FIGURE 8 T55 FIRST G.P. TURBINE RADIAL GROWTHS

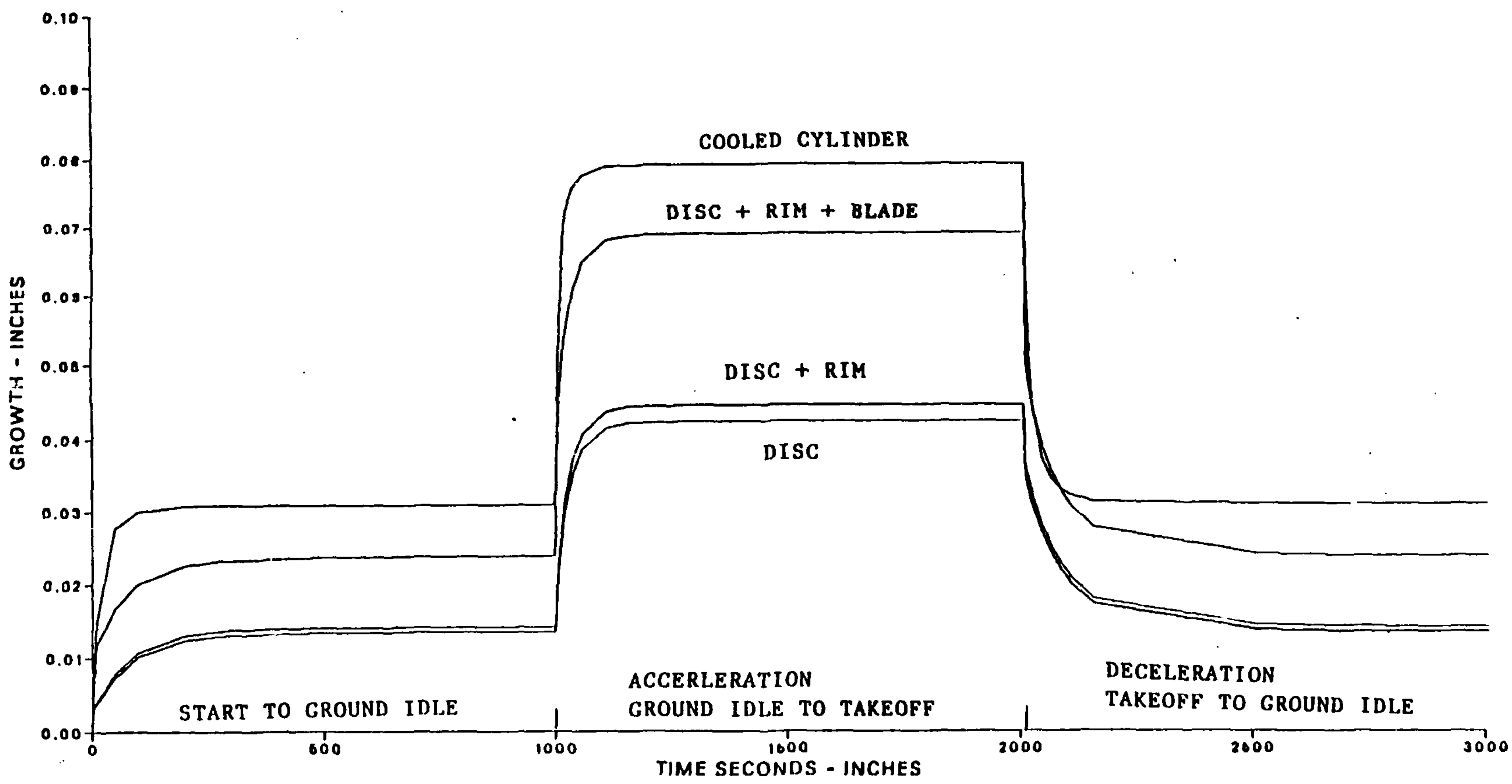


FIGURE 9. T55 SECOND G.P. TURBINE RADIAL GROWTHS

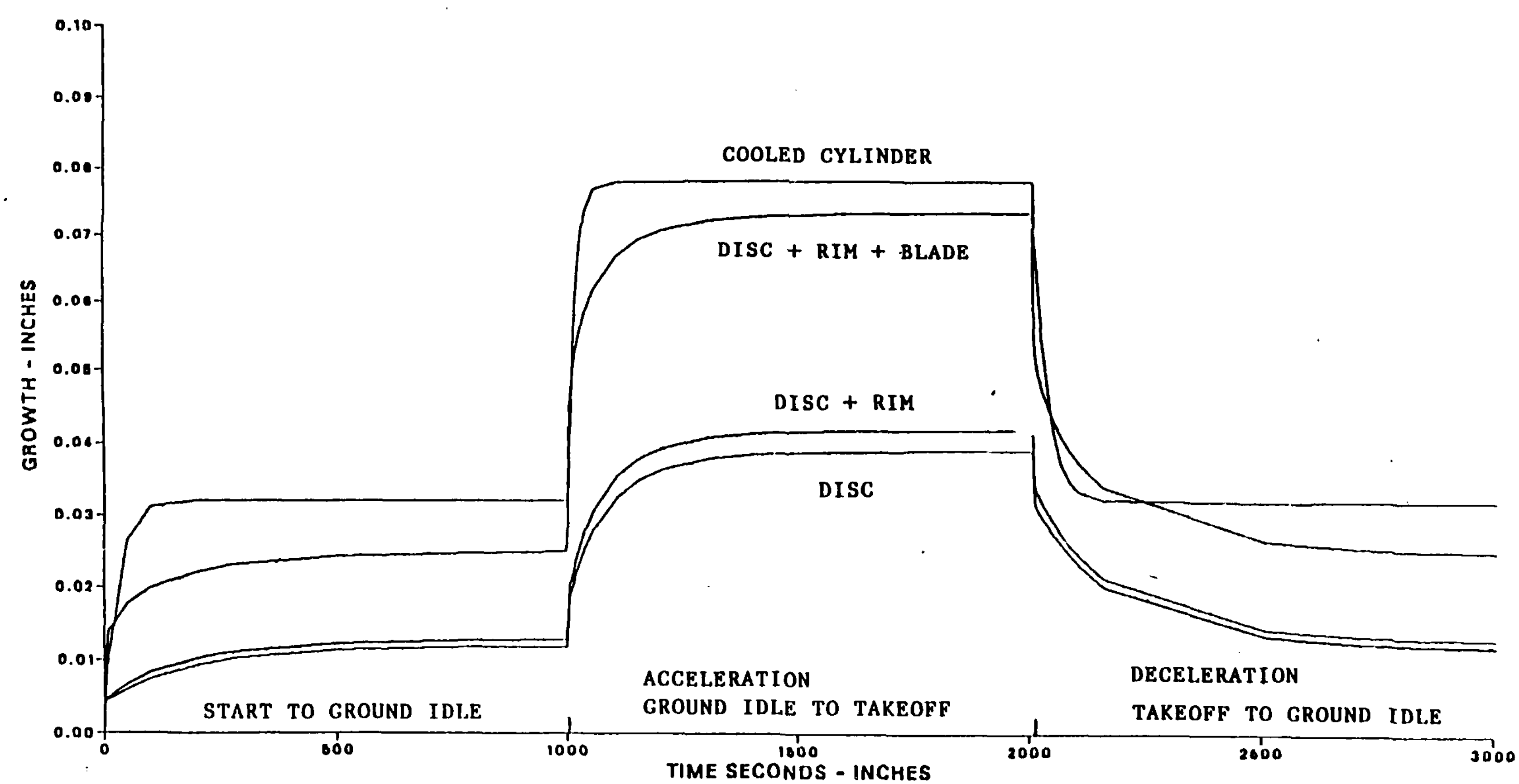


FIGURE 10. T55 FIRST G.P. TURBINE TIP CLEARANCE

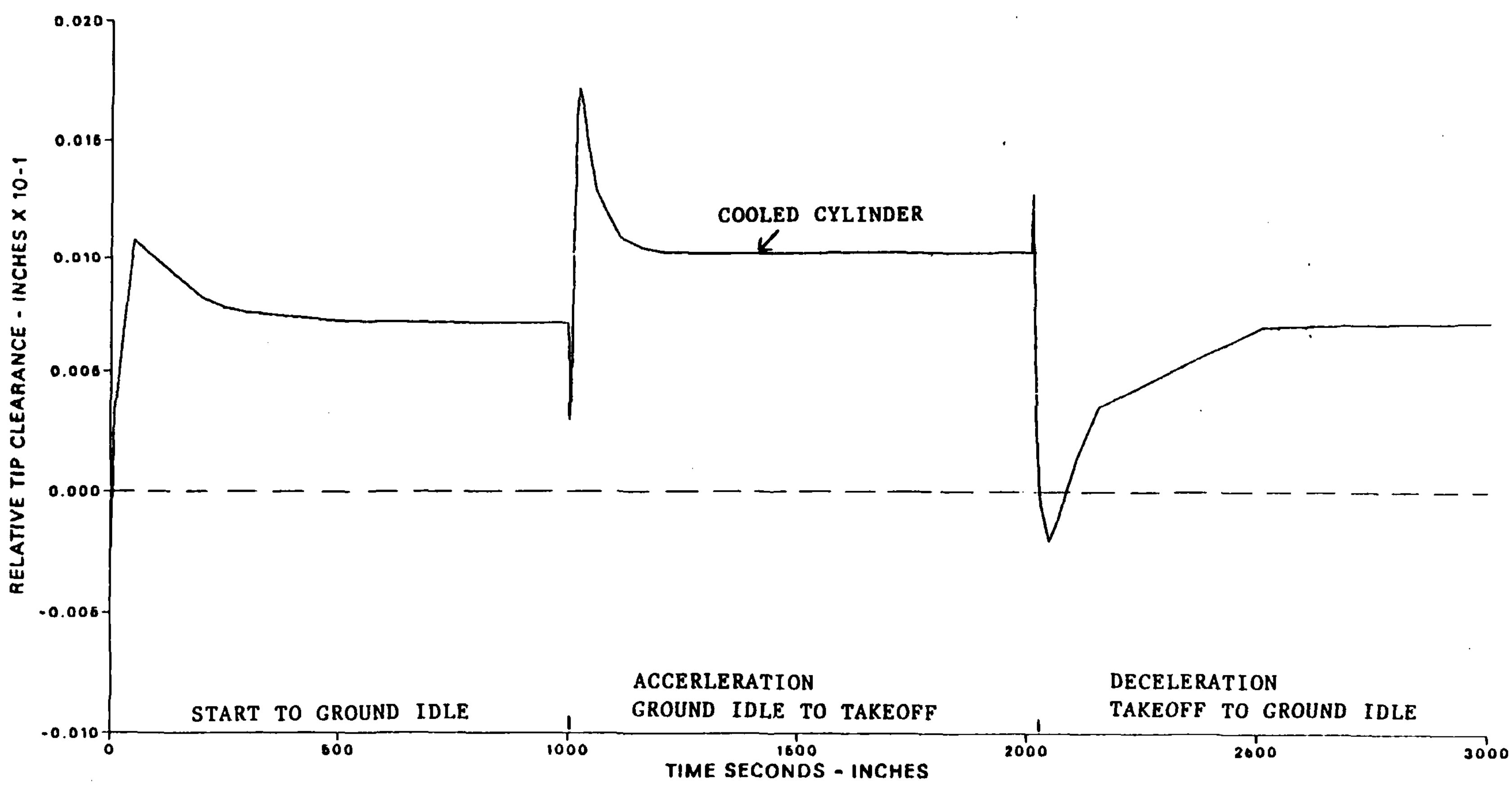


FIGURE 11. T55 SECOND G.P. TURBINE TIP CLEARANCE